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Frieze Group in Generating Traditional Cloth Motifs of the East Nusa Tenggara Province

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ABSTRACT

Ethnomathematics studies the relationship between mathematics and culture. Indonesia has many traditional cultures. One of them is traditional cloth. The traditional cloth from East Nusa Tenggara (NTT) province is called *tenun ikat*. Since the motif of *tenun ikat* consists of symmetrical and repeated patterns, it can be generated using Frieze groups. The Frieze groups are the plane symmetry groups of patterns whose subgroups of translations are isomorphic to $\mathbb{Z}$. There are seven groups in the Frieze groups, i.e., F_1, F_2, F_3, F_4, F_5, F_6, and F_7. Translation, reflection, rotation, and glide reflection are the transformation used in the Frieze groups. In this paper, Frieze groups are used to generate digital *tenun ikat* motifs from the basic pattern. Since one piece of original *tenun ikat* may consist of some basic patterns, the basic patterns are identified first, and then each of them is generated into the desired pattern, according to the suitable Frieze groups. Furthermore, a GUI Matlab program is developed to generate the Frieze groups. Three motifs of *tenun ikat* are presented to demonstrate the implementation of Frieze groups. With the Frieze group, users can generate other patterns from a basic pattern, so users can generate new motifs of *tenun ikat* without leaving the cultural characteristics of NTT province.

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A. INTRODUCTION

Repeated patterns are often encountered in everyday life (Starinsky & Hoffmeyer, 2008), for example in cloth, woven bamboo, paving roads, tiles, wall ornaments, etc. The repeated pattern is basically formed from a pattern that is transformed in such a way, so that it forms a unified pattern. Four lines can form a square, six equilateral triangles combine into a hexagon, some honeycombs can be combined into hexagons, and the right footprint and left footprint can form a pair of footprints. The repeating pattern is symmetric. A square is symmetric, right and left, top and bottom have the same size. Likewise with the footprints, right and left must be symmetrical. Other examples that have symmetrical properties include butterflies, scissors, and even the human body is symmetrical (Nataliani et al., 2021).

Indonesia is a country consisting of various cultures (Zarbaliyev, 2017). Each culture has different characteristics, which can be seen and reflected in the local language, traditional cloth, traditional weapons, folk songs, local dances, traditional ceremonies, etc. Especially for traditional cloth, each province in Indonesia has a different motif. Traditional clothes describe various ethnic, religions, and social classes (Gual, 2021).

Tenun ikat is a traditional cloth of several regions in the East Nusa Tenggara (NTT) province, such as Flores, Sumba, Timor, Alor, Rote, and Sawu. *Tenun ikat* is typically used for clothing in everyday life, clothing in traditional dances or ceremonies, dowry in marriage, an indicator of social status, transaction tools, and a gift (Nainupu, 2018). It is made by weaving threads and making the motif by tying it with a rope according to a particular pattern before being dipped in dye. *Tenun ikat* from 22 regions in NTT province has various motif designs, colors, and sizes, representing their characteristics. The motifs are related to the customs, beliefs, culture, and habits of the local community (Maghiszha, 2019). *Tenun ikat* from Sumba and Rote regions generally use animal and leaf motifs, respectively. *Tenun ikat* from Timor region is in the form of silk and has embroidery. Alor region uses natural colors from plants and marine life (Salma et al., 2018). Some motifs of *tenun ikat* are shown in Figure 1.

Figure 1. Some Traditional Cloth Motifs of the East Nusa Tenggara, (a) Flores; (b) Sawu; (c) East Sumba; (d) Ende

Weaving the *tenun ikat* becomes a part of the daily life of people in NTT province, especially women. In this modern era, *tenun ikat* is not only used by the people of NTT province, but also by people outside of NTT province. *Tenun ikat* has even appeared at Culture New York Fashion Week in 2017 and Paris Fashion Week in 2018 (Redaksi PI, 2021). Some problems in the weaving process of *tenun ikat* are the expensive materials and long processing times (Administrator, 2019), which made the price of *tenun ikat* expensive. Furthermore, some of the younger generations do not want to continue the weaving culture. This can lead to the extinction of the *tenun ikat* culture. With the advancement of technology, *tenun ikat*, specifically, its motifs, can be preserved or maintained even developed further. Motifs of *tenun ikat* can be generated using mathematical formulas and digitized using a computer program.

From Figure 1, it can be seen that the motif of *tenun ikat* has the characteristic of a geometric pattern. A geometric pattern is a design with a certain pattern, repeating regularly. Ethnomathematics is the study of the relationship between mathematics and culture (Hidayati & Prahmana, 2022). Ethnomathematics helps to build meta-awareness about the role of mathematical knowledge in mathematical society and culture (Rosa et al., 2017). Ethnomathematics can be used to explore mathematics related to culture. Ethnomathematics is a daily mathematical representation or mathematics associated with cultures. Using ethnomathematics, Javanese culture, especially batik, other than consists of philosophy and deep cultural value, it also consists of mathematics concepts, such as geometry transformation concepts (Risdiyanti & Prahmana, 2017). The traditional house and traditional music instrument of Biak can be explored by using ethnomathematics, where the shape of the roof of the traditional house is rectangular, half elliptical and triangular trapezoid, and the traditional music instrument looks like the two most belted cones combined (Sroyer et al., 2018).

Some motifs in the *tenun ikat* can be generated by applying mathematical formulas. One of the mathematical formulas that can be applied is crystallographic patterns. Some research about finding the crystallographic patterns for traditional clothes can be found in (De Las Peñas et al., 2018; Hobanthad & Prajonsant, 2021; Kartika et al., 2022; Libo-On, 2019; Vasquez et al., 2020). Another mathematical formula that can be used is Frieze groups (Davvaz, 2021). Frieze groups aim to design some repetitions in one dimension, into decorative arts. Some research using Frieze groups concerning culture are shown in Table 1.

Table 1. Research about Frieze Groups

No	Title	Result
1	Frieze Patterns on Papua Batik (Nggumbe et al., 2018)	In one motif of Papua batik, there are several Frieze patterns.
2	Frieze Groups on Saman Dance (Oktavianto et al., 2018)	In Saman dance, there are two Frieze groups, i.e., F_1 and F_3.
3	Frieze Groups on Mosque Decorative Arts (Rahmawati et al., 2018)	Not all patterns in mosque decorative arts can be classified into seven Frieze patterns and not all seven frieze patterns always exist in one mosque decorative arts.
4	Symmetry Patterns: An Analysis on Frieze Patterns in Malay Telepuk Fabric (Abdullah et al., 2019)	It is proven that there are geometrical and symmetrical patterns in the Telepuk fabric.
5	Crystallographic and Frieze Groups Structures in Hablon (Libo-On, 2019)	All Frieze patterns are clearly visible in Hablon.
6	Frieze Group Pattern in Buyung Dance Formation (Andriani et al., 2020)	The formations of Buyung dance are identical to the Frieze group patterns.
7	Exploring Motifs in Towe Songke, Manggaraian Ethnic Woven Fabric, in Mathematics Perspective (Makur et al., 2020)	Most motifs in Towe Songke have group F_7 because they can be seen as translation, horizontal reflection, vertical reflection and half turn rotation symmetry.
8	One-color Frieze Patterns in Friendship Bracelets: A Cross-Cultural Comparison (Koss, 2021)	Users are creating designs based on symmetry preferences of their local culture.
9	Analysis of Frieze Patterns Concepts in Pua Kumbu (Truna et al., 2021)	Patterns based on geometry and symmetry exist in the ways Pua Kumbu is created.
10	Korean Traditional Patterns: Frieze and Wallpaper (Shin et al., 2021)	Two Korean traditional music instruments play the seven frieze patterns.
11	Frieze Pattern on Shibori Fabric (Puspasari et al., 2022)	There are Frieze patterns in the Shibori motif, i.e., F_1, F_2, F_3, F_4, F_5, F_6, and F_7.
12	Analysis of Frieze and Crystallographic Patterns of North Sumatran Malay *Songket* Textile (Kartika et al., 2022)	Four Frieze patterns can be recognized on the North Sumatran Malay *songket* textile, i.e., F_1, F_3, F_5, and F_7.

Indonesian cultures need to be preserved, including the *tenun ikat* from NTT. Table 1 shows the use of Frieze groups in some regions, but none of them has discussed *tenun ikat*, even though it is one of Indonesian cultures that is recognized in the world (Redaksi impresinews.com, 2021; Redaksi Kompas, 2019). Most of the *tenun ikat* weavers are elderly women, so it is feared that there will be no younger generation who understands the culture of *tenun ikat* (Azizah, 2021). In addition, the high price of *tenun ikat* (Novemyleo, 2020) makes buyers, especially tourists who just want to buy souvenirs, unable to buy *tenun ikat*. Therefore, the motifs of *tenun ikat* will be analyzed, so that the motifs can be preserved and also vary, without leaving their original culture. Besides that, the digitized motifs of *tenun ikat* allow weavers to use them as stamped motifs on the fabric, so the production cost can be minimized. The goal of this paper is to explore and analyze the motifs of *tenun ikat* from the mathematical perspective, especially geometry elements in the motifs of *tenun ikat* using Frieze groups. Furthermore, a computer program is made to generate the motif from a basic pattern, so users can generate new motifs of *tenun ikat* without leaving the cultural characteristics of NTT province.

B. METHODS

In this paper, Frieze groups are used to identify and generate the basic pattern of *tenun ikat*. The Frieze groups are the plane symmetry groups of patterns whose subgroups of translations are isomorphic to $\mathbb{Z}$. Transformation used in the Frieze group can be seen below. Let $\begin{pmatrix} a \\ b \end{pmatrix}$ be the origin point and $\begin{pmatrix} a' \\ b' \end{pmatrix}$ be the result point.

1. Translation. The matrix transformation for translation is $\begin{pmatrix} a' \\ b' \end{pmatrix} = \begin{pmatrix} a+h \\ b+k \end{pmatrix}$.
2. Reflection. The matrix transformation for vertical reflection at $x = 0$ is $\begin{pmatrix} a' \\ b' \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} a \\ b \end{pmatrix}$, while at $x = h$ is $\begin{pmatrix} a' \\ b' \end{pmatrix} = \begin{pmatrix} 2h \\ 0 \end{pmatrix} - \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} a \\ b \end{pmatrix}$. The matrix transformation for horizontal reflection at $y = 0$ is $\begin{pmatrix} a' \\ b' \end{pmatrix} = \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} a \\ b \end{pmatrix}$, while at $y = k$ is $\begin{pmatrix} a' \\ b' \end{pmatrix} = \begin{pmatrix} 0 \\ 2k \end{pmatrix} - \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} a \\ b \end{pmatrix}$.
3. Rotation. The matrix transformation for rotation at (0,0) is $\begin{pmatrix} a' \\ b' \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}\begin{pmatrix} a \\ b \end{pmatrix}$, while the matrix transformation at (m, n) is $\begin{pmatrix} a' \\ b' \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}\begin{pmatrix} a-m \\ b-n \end{pmatrix} + \begin{pmatrix} m \\ n \end{pmatrix}$. Rotations can be rotations of orders two, three, four, and six-fold, where the angle of rotations is 180°, 120°, 90°, and 60°, respectively.
4. Glide reflection. Glide reflection is transformation for both translation and reflection. There are seven patterns in the Frieze groups (Gallian, 2021) as shown in Table 2.

Table 2. Frieze Group

Group	Symbol	Formula	Description
F_1 (hop)	11	$F_1 = \{x^n \mid n \in \mathbb{Z}\}$, where: x : translation	Translation in horizontal directions
F_2 (step)	1g	$F_2 = \{x^n \mid n \in \mathbb{Z}\}$, where: x : glide reflection	Glide reflection
F_3 (sidle)	m1	$F_3 = \{x^n y^m \mid n \in \mathbb{Z}, m = 0 \text{ or } m = 1\}$, where: x : translation y : vertical reflection	Translation and vertical reflection
F_4 (spinning hop)	12	$F_4 = \{x^n y^m \mid n \in \mathbb{Z}, m = 0 \text{ or } m = 1\}$, where: x : translation	Translation and two-fold rotation

Group	Symbol	Formula	Description
		y : rotation of 180º	
F_5 (spinning sidle)	mg	$F_5 = \{x^n y^m \mid n \in \mathbb{Z}, m = 0 \text{ or } m = 1\}$, where: x : glide reflection y : rotation of 180º	Glide reflection and two-fold rotation
F_6 (jump)	1m	$F_6 = \{x^n y^m \mid n \in \mathbb{Z}, m = 0 \text{ or } m = 1\}$, where: x : translation y : horizontal reflection	Translation and horizontal reflection
F_7 (spinning jump)	mm	$F_7 = \{x^n y^m z^k \mid n \in \mathbb{Z}, m = 0 \text{ or } m = 1, k = 0 \text{ or } k = 1\}$, where: x : translation y : horizontal reflection z : vertical reflection	Translation, horizontal and vertical reflection

Washburn and Crowe (1988) proposed an algorithm that can be used to identify seven Frieze groups by using flowchart (Gallian, 2021), as seen in Figure 2.

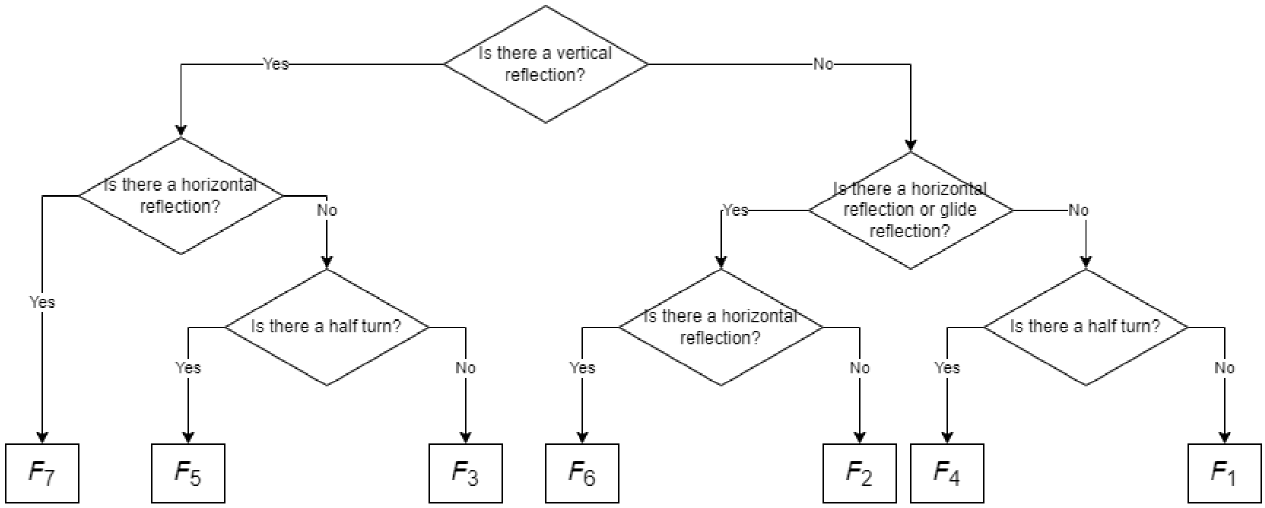


Figure 2. Flowchart for Identifying Frieze Groups

For example, one basic pattern shown in Figure 3 is used. From this basic pattern, the seven patterns of Frieze groups can be generated as shown in Figures 4, Figures 5, Figures 6, Figures 7, Figures 8, Figures 9 dan Figures 10.

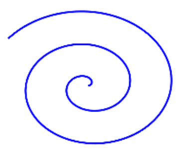


Figure 3. Basic Pattern

Group F_1. Let x denotes a translation to the right of one unit, then the group F_1 is generated as shown in Figure 4.

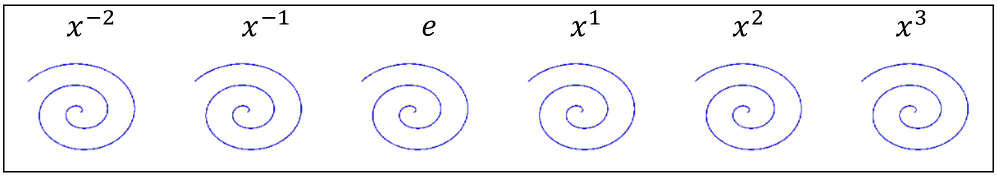


Figure 4. Group F_1

1. Group F_2. Let x denotes a glide reflection, then the group F_2 is generated as shown in Figure 5.

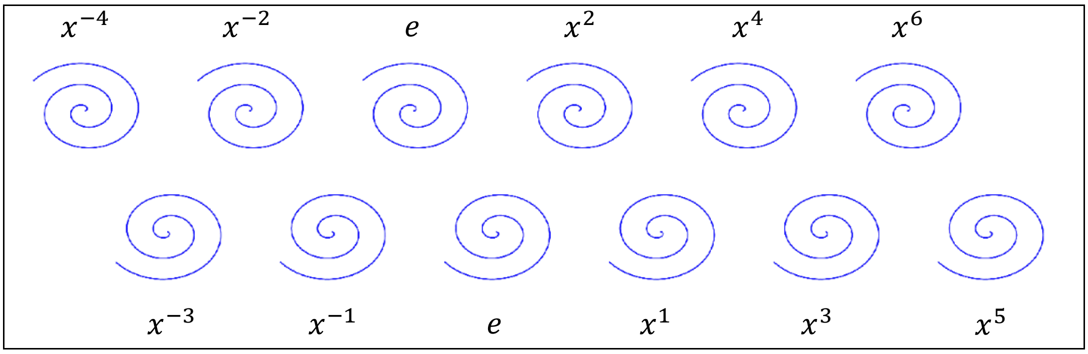


Figure 5. Group F_2

Group F_3. Let x denotes a translation to the right of one unit and y denotes a vertical reflection, then the group F_3 is generated as shown in Figure 6.

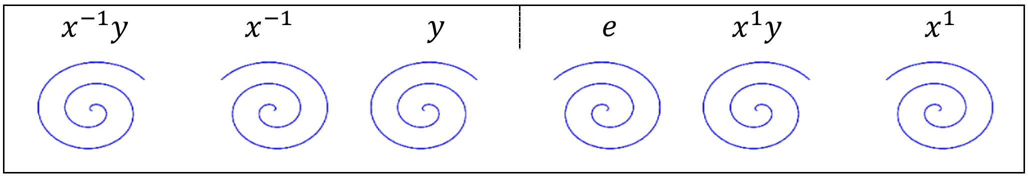


Figure 6. Group F_3

Group F_4. Let x denotes a translation to the right of one unit and y denotes a rotation of 180°, then the group F_4 is generated as shown in Figure 7.

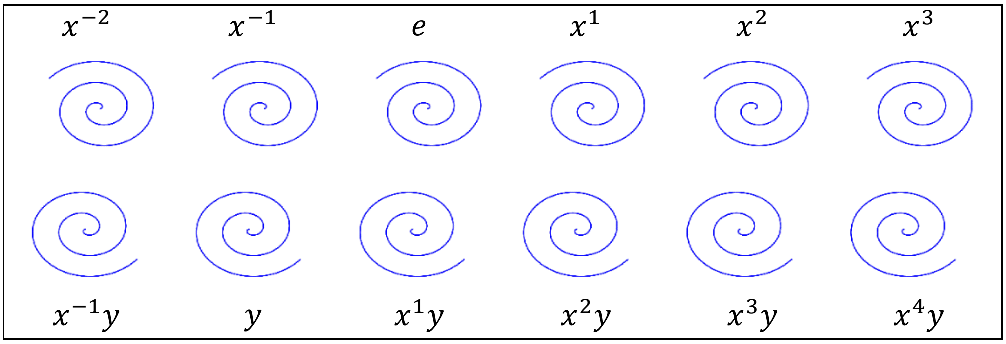


Figure 7. Group F_4

Group F_5. Let x denotes a glide reflection and y denotes a rotation of 180°, then the group F_5 is generated as shown in Figure 8.

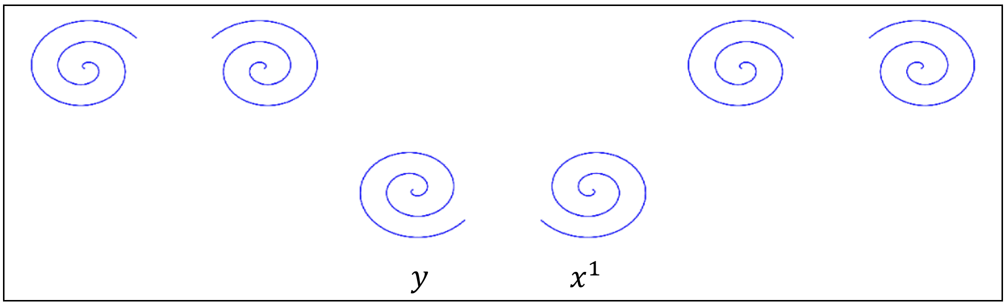


Figure 8. Group F_5

Group F_6. Let x denotes a translation to the right of one unit and y denotes a horizontal reflection, then the group F_6 is generated as shown in Figure 9.

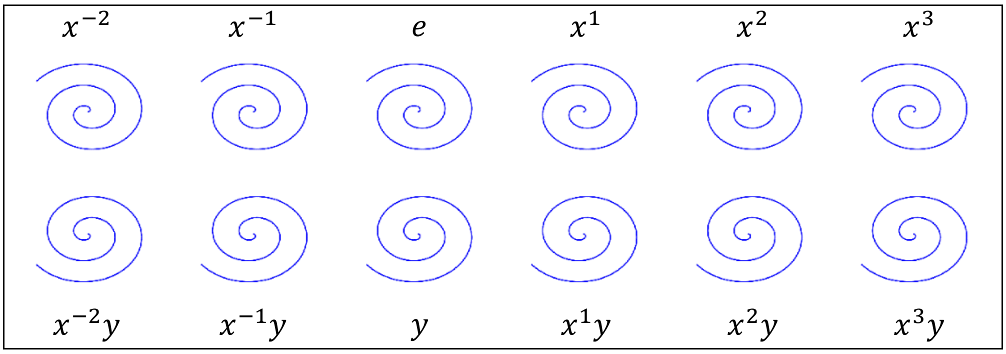


Figure 9. Group F_6

Group F_7. Let x denotes a translation to the right of one unit, y denotes a horizontal reflection, and z denotes a vertical reflection, then the group F_7 is generated as shown in Figure 10.

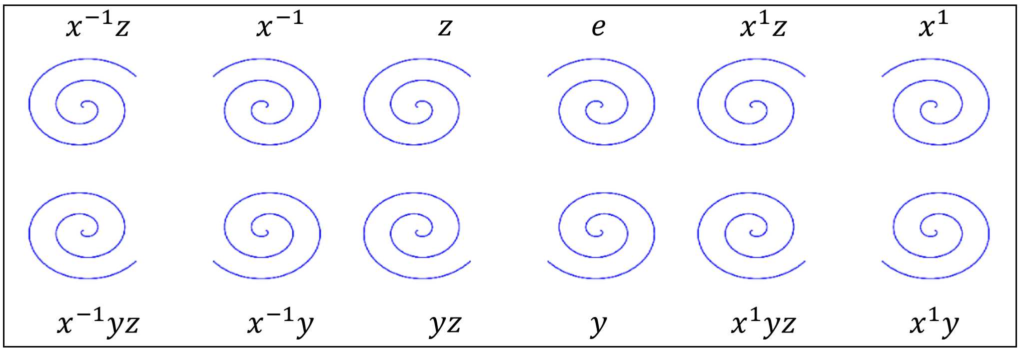


Figure 10. Group F_7

The research method in this paper can be shown in Figure 11. The process starts with identifying the basic pattern of a fabric motif, if needed. If a basic pattern that doesn't follow a pattern that already exists is wanted, then the process is continued on generating the basic pattern into a new pattern using Frieze groups. Since some new patterns can be combined into one pattern, then it can generate more into a new pattern using Frieze groups, as shown in Figure 11.

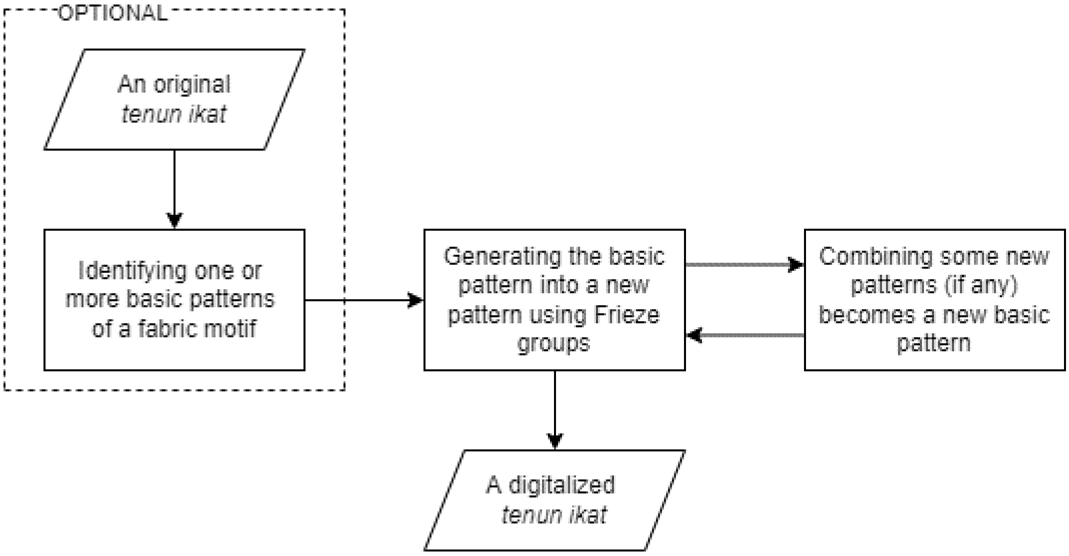


Figure 11. Research Method

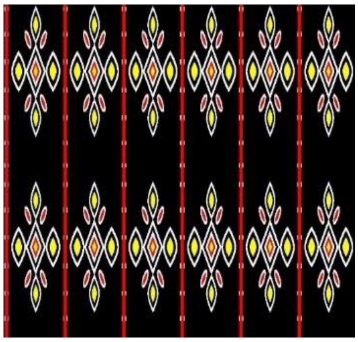
C. RESULT AND DISCUSSION

Several tasks carried out in this article are (1) identifying the basic pattern of *tenun ikat*, (2) generating a pattern from the basic pattern using Frieze groups, (3) applying a pattern generation using GUI Matlab. In this study, three motifs of *tenun ikat* from NTT province are given as examples to prove that Frieze groups can be used to generate digitized *tenun ikat*. The mathematical formulas to generate the basic pattern into the result pattern using the Frieze groups are also explained.

1. Motif 1

The original motif is shown in Figure 12(a). The motif generation can be seen in Table 3 and the result using the program is shown in Figure 12(b).

(a)



(b)

Figure 12. Motif 1 (a) Original; (b) Result from Program Generation

The generation using the Frieze group is described in Table 4. The basic pattern 1 is identified from the result pattern 1 using the flowchart in Figure 3. From the flowchart, the result pattern 1 belongs to the group F_7, where the basic pattern 1 is reflected horizontally, and then translated with vertical reflection, and also translated with vertical and horizontal reflections. Furthermore, the basic pattern 2 generates the result pattern 2 with a group of F_6, where the basic pattern 2 is translated and reflected vertically, as shown in Table 3.

Table 3. The Generation of Motif 1

No.	Basic Pattern	Group	Mathematical Explanation	Result Pattern
1.		F_7	$\{x^n y^m z^k \mid n = 0, m = 0,1,\ k = 0,1\}$, where x denotes a translation to the right of one unit, y denotes a horizontal reflection, and z denotes a vertical reflection.	
2.		F_6	$F_6 = \{x^n y^m \mid n = 0, \ldots, 5, m = 0,1\}$, where x denotes a translation to the right of one unit and y denotes a horizontal reflection	

2. Motif 2

The original motif is shown in Figure 13(a). The motif generation can be seen in Table 4 and the result using the program is shown in Figure 13(b). As seen in Table 4, the motif in Figure 13(a) consists of two parts, the first part as shown in the first row and the second part as shown in the second row. The final result is obtained by combining the two parts, as shown in the third row, as shown in Figure 13.

(a) (b)

Figure 13. Motif 2 (a) Original; (b) Result from Program Generation

For the first part, the result pattern 1 can be obtained from the basic pattern 1 by generating group F_7. The second part is generated from the basic pattern 2 using a group of F_7. Furthermore, the first part and the second part are combined, becoming the basic pattern 3. Using a group of F_7, the result is shown in the result pattern 3. Finally, using a group of F_1, the result pattern 3 is translated to the right one unit, which becomes the result pattern 4, as shown in Table 4.

Table 4. The Generation of Motif 2

No.	Basic Pattern	Group	Mathematical Explanation	Result Pattern
1.		F_7	$\{x^n y^m z^k \mid n = 0, m = 0,1,\ k = 0,1\}$, where x denotes a translation to the right of one unit, y denotes a horizontal reflection, and z denotes a vertical reflection.	

No.	Basic Pattern	Group	Mathematical Explanation	Result Pattern
2.		F_7	$\{x^n y^m z^k \mid n = 0, m = 0,1,\ k = 0,1\}$, where x denotes a translation to the right of one unit, y denotes a horizontal reflection, and z denotes a vertical reflection.	
3.		F_7	$\{x^n y^m z^k \mid n = 0,\ m = 0,1,\ k = 0,1\}$, where x denotes a translation to the right of one unit, y denotes a horizontal reflection, and z denotes a vertical reflection.	
4.		F_1	$\{x^n \mid n = 0,1\}$, where x denotes a translation to the right of one unit	

3. Motif 3

The original motif is shown in Figure 14(a). The motif generation can be seen in Table 5 and the result using the program is shown in Figure 14(b). Table 5 shows the generation in each step. As shown in Figure 14.

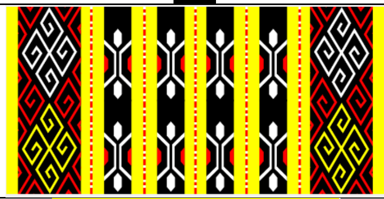
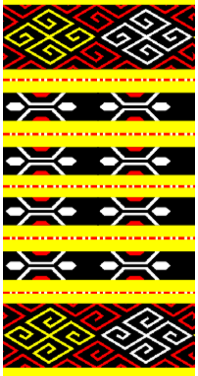
(a) (b)

Figure 14. Motif 2 (a) Original; (b) Result from Program Generation

The basic pattern 1 is generated using group F_7, becomes the result pattern 1. Then, by using a group of F_6, the result pattern 1 is reflected horizontally and becomes the result pattern 2. Furthermore, the result pattern 2 is combined with another pattern, as can be seen in the basic pattern 3. Using a group of F_3, the basic pattern 3 is reflected vertically, and becomes the result pattern 3. Finally, the result pattern 3 is translated to the right of one unit, using a group of F_1, as shown in the result pattern 4. As shown in Table 5.

Table 5. The Generation of Motif 3

No.	Basic Pattern	Group	Mathematical Explanation	Result Pattern
1.		F_7	$\{x^n y^m z^k \mid n = 0, m = 0,1,\ k = 0,1\}$, where x denotes a translation to the right of one unit, y denotes a	

No.	Basic Pattern	Group	Mathematical Explanation	Result Pattern
			horizontal reflection, and z denotes a vertical reflection.	
2.		F_6	$F_6 = \{x^n y^m \| n = 0, m = 0,1\}$, where x denotes a translation to the right of one unit and y denotes a horizontal reflection	
3.		F_3	$\{x^n y^m \| n = 0, m = 0,1\}$, where x denotes a translation to the right of one unit and y denotes a vertical reflection	
4.		F_1	$\{x^n \| n = 0,1\}$, where x denotes a translation to the right of one unit	

Furthermore, Graphical User Interface (GUI) in Matlab is made to generate a basic pattern into the result pattern. Figure 15 is the GUI design for the pattern generation. Users can enter a motif from ”Open” button and the motif will be displayed on the axes. One Frieze group is chosen from the ”F1” until ”F7” buttons, to get the results. The result will be displayed on the new window and users can save the result with ”Save” button, as shown in Figure 15.

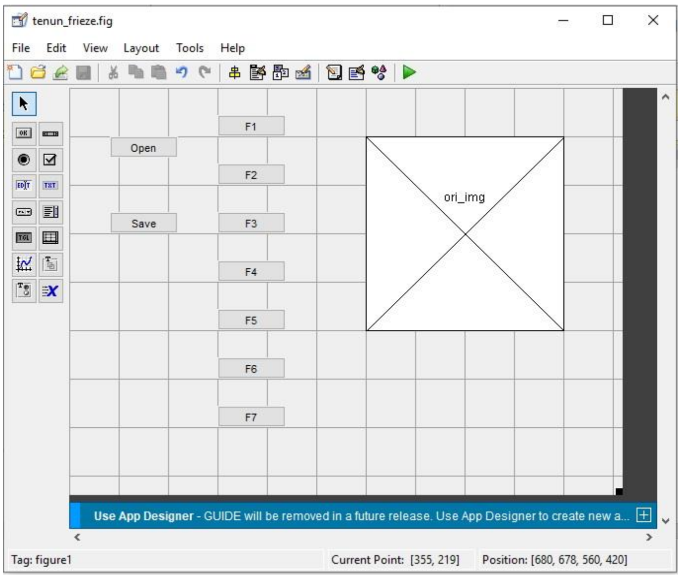


Figure 15. GUI Matlab Design for Generating Frieze Patterns

Motif 3 is taken for the example. Let F_3 is applied to the 3rd basic pattern from Table 5 (as shown in Figure 16(a)), then the result can be seen in Figure 16(b).

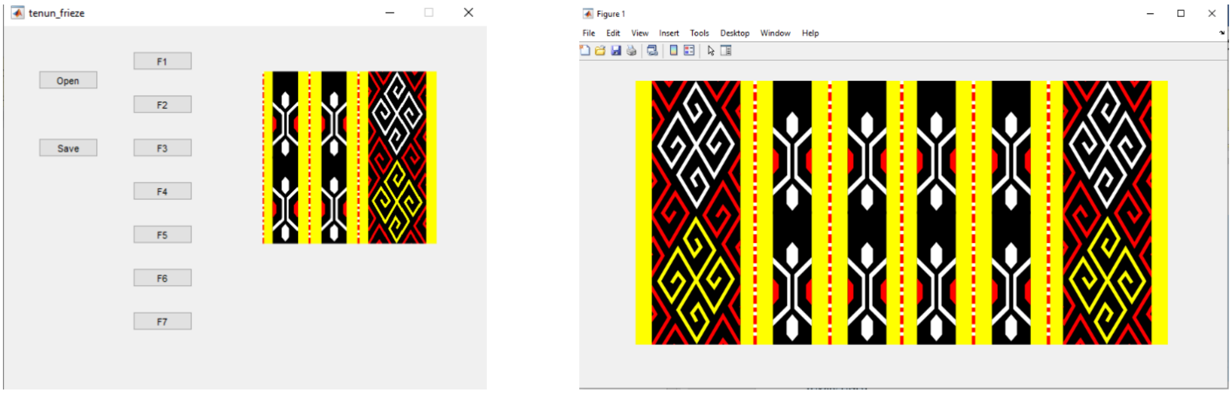


Figure 16. (a) GUI Matlab for Generating Motif 3; (b) The Generating Result of Motif 3 using GUI Matlab

The Matlab code for F_3 is shown in Code 1 below, where image is the basic pattern, F is the matrix for the basic pattern, G is the matrix for the horizontal reflection, and Z is the result.

Code 1. Matlab Code for F_3 Group

```
F1=double(image);
s=size(F1);
G1=zeros(s(1),s(2),s(3));
for i=1:s(1)
    j=1:s(2);
    k=s(2)-j+1;
    G1(i,k,:)=F1(i,j,:);
end
G=uint8(G1);
F=uint8(F1);
Z=[G F];
```

As explained in the Introduction, the preservation and innovation of *tenun ikat* is needed, so that *tenun ikat* does not become extinct. By identifying the existing of *tenun ikat* motifs and combining them with the Frieze groups, in this digital era. some new interesting motifs can be created and can be a reference for weavers. From the results of the several motifs identification, it turns out that the Frieze groups can be used to generate *tenun ikat*, since the motifs of *tenun ikat* contains of repeated translation, reflection, and rotation.

D. CONCLUSION AND SUGGESTIONS

Ethnomathematics combines mathematics and culture. In this paper, the motifs of traditional cloth from NTT province are generated using mathematical formula, i.e., Frieze groups. Three motifs are presented. Each motif consists of some basic patterns. The basic patterns are identified and then generated into the desired pattern using Frieze groups.

Furthermore, a GUI Matlab is developed to generate Frieze groups. For future research, the group identification will be conducted using Convolutional Neural Network.

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